SPACE COMMUNICATIONS AND NAVIGATION

Opportunistic MSPA: FY'17-18 Progress & Plans

OMSPA Technical Interchange Meeting, Morehead State University

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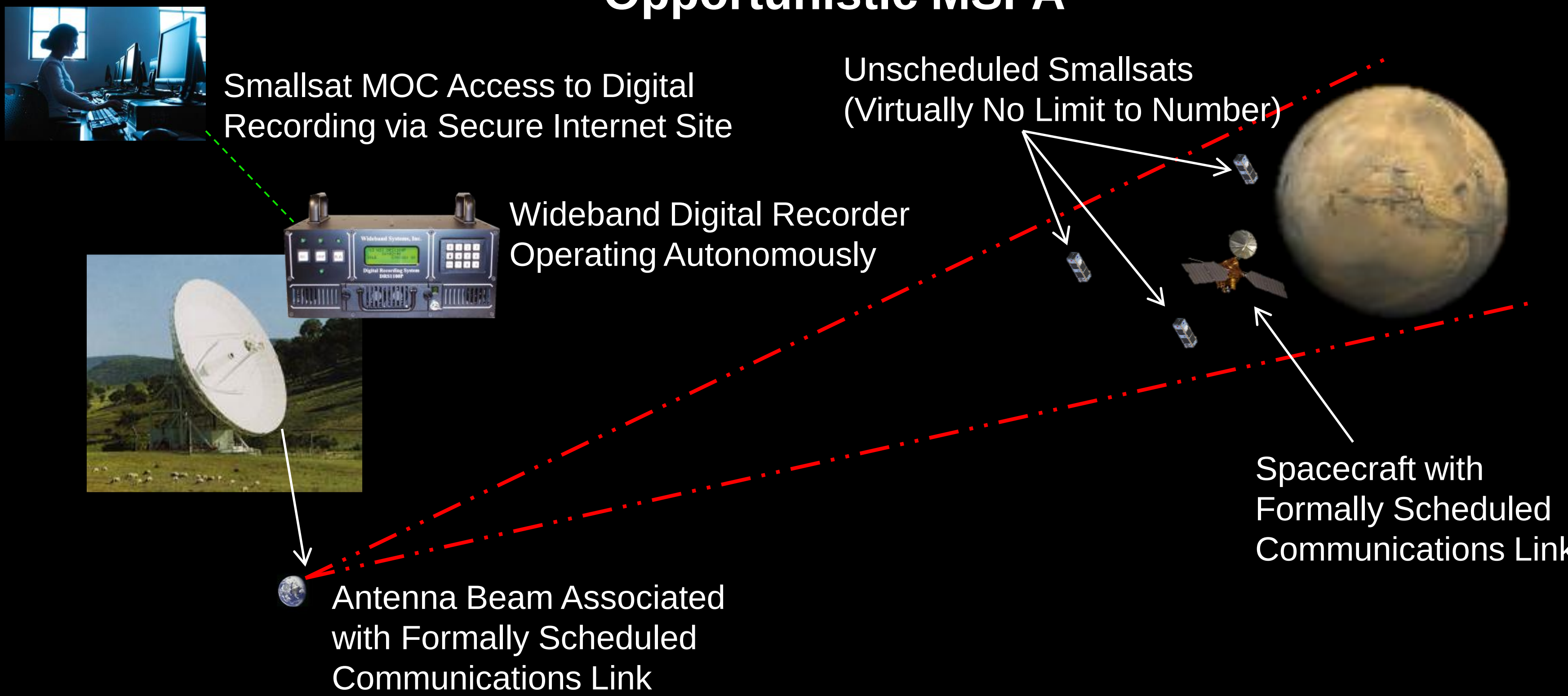
OMSPA Overview (1/2)

Opportunistic MSPA



Everything received through the antenna beam is digitally recorded. Smallsats transmit open loop when in a host spacecraft's beam. Smallsat MOCs retrieve relevant portion of digital recording for subsequent demodulation and decoding, or subscribe to a service that does it for them.

OMSPA Overview (2/2)

- **For further information about the OMSPA Proof-of-Concept Demonstration #1, see:**

  Douglas S. Abraham, Susan G. Finley, David P. Heckman, Norman E. Lay, Cindy M. Lush, and Bruce E. MacNeal, "Opportunistic MSPA Demonstration #1: Final Report," Interplanetary Network Progress Report, 42-200 (February 2015).

OMSPA Demonstration Plan

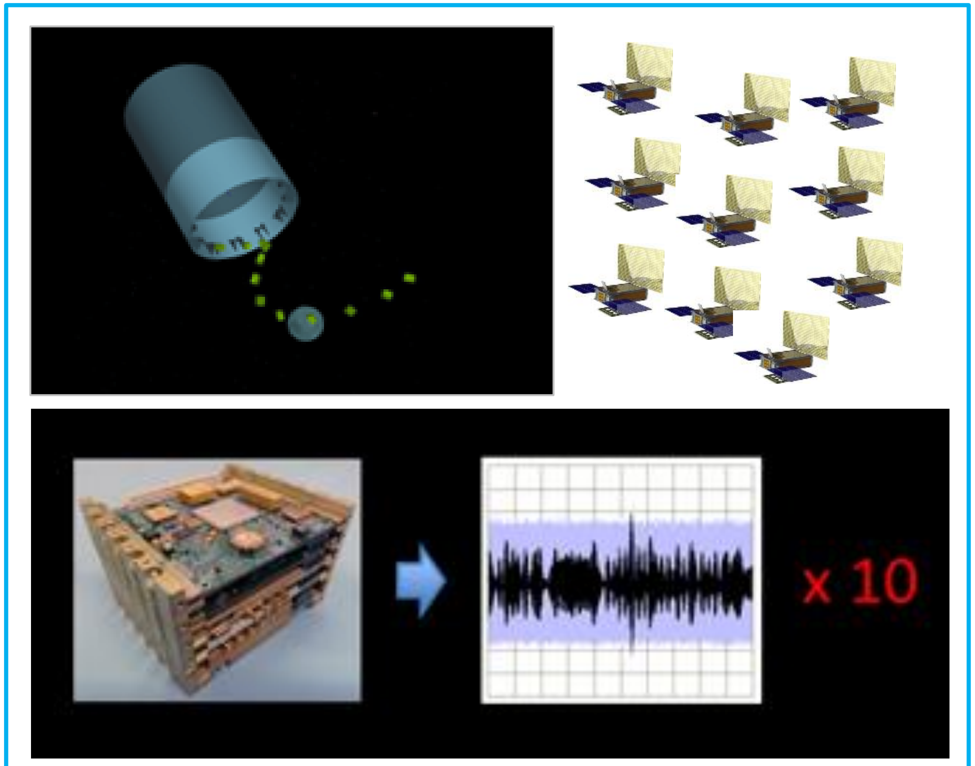
Demo 2 Done, 3 In Progress	OMSPA Proof-of-Concept Demonstrations 2 and 3 – Multiple Cubesats with a Strong-Signal Spacecraft	4/28/2017
Done	OMSPA Software Receiver Prototype that Includes Doppler Extraction	4/28/2017
Beginning	Prototype OMSPA User Interface – “One-Stop Shop” for Unscheduled, Opportunistic Use of Scheduled Beams (Test via Simulated MOCs at JPL and MSU)	9/29/2017
Future	OMSPA Proof-of-Concept Demonstration – JPL & MSU MOCs (via DSN and 21m station) for Single Cubesat with a Strong-Signal Spacecraft (e.g., LRO + THEMIS B or C)	12/29/2017
Future	OMSPA Proof-of-Concept Demonstration – JPL & MSU MOCs (via DSN and 21m station) for Multiple Cubesats with a Strong-Signal Spacecraft (e.g., InSight + MarCO A and B)	5/5/2018

Topics

- **OMSPA Proof-of-Concept Demonstrations 2 and 3 – Multiple Cubesats with a Strong-Signal Spacecraft** — **4/28/2017**
- **OMSPA Software Receiver Prototype that Includes Doppler Extraction** — **4/28/2017**
- **Prototype OMSPA User Interface – “One-Stop Shop” for Unscheduled, Opportunistic Use of Scheduled Beams (Test via Simulated MOCs at JPL and MSU)** — **9/29/2017**
- **OMSPA Proof-of-Concept Demonstration – JPL & MSU MOCs (via DSN and 21m station) for Single Cubesat with a Strong-Signal Spacecraft (e.g., LRO + THEMIS B or C)** — **12/29/2017**
- **OMSPA Proof-of-Concept Demonstration – JPL & MSU MOCs (via DSN and 21m station) for Multiple Cubesats with a Strong-Signal Spacecraft (e.g., InSight + MarCO A and B)** — **5/5/2018**

OMSPA Proof-of-Concept Demonstration 2 (1/3)

Data Recovery from 10 Simulated, In-Beam Iris Radio Cubesats



- **Objective:** Demonstrate that OMSPA, during cubesat deployments from secondary payload adapters, can provide a backup capability for retrieving mission-critical data and one-way Doppler information in the event that a scheduled pass fails to occur as planned.

OMSPA Proof-of-Concept Demonstration 2 (2/3)

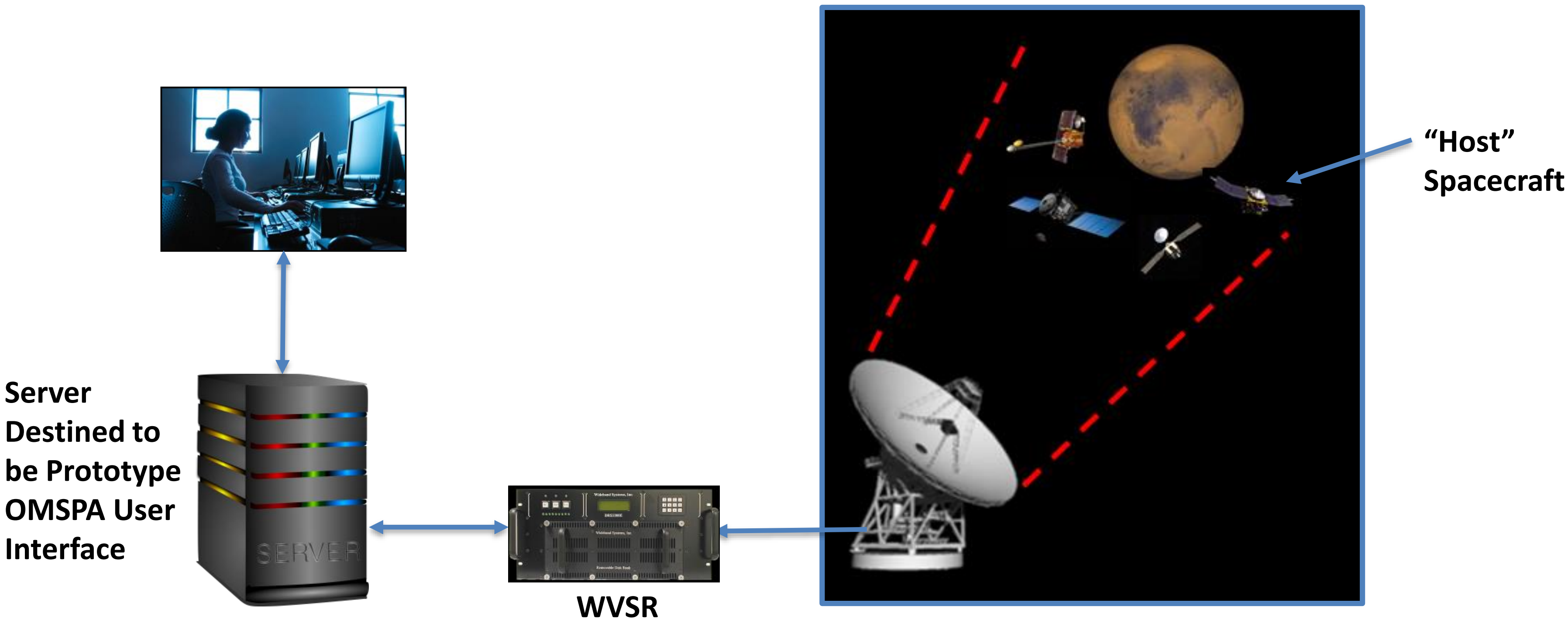
- **Demonstration Plan:**
  - Update/demonstrate OMSPA Software Receiver capability to handle Iris modulation and coding.
    - BPSK with NRZ, with or without a subcarrier (up to 65 kbps so far); BPSK Bi-Phase (Manchester) (up to 65 kbps so far); QPSK (up to 1.3 Mbps so far)
    - Convolutional 7-1/2; Convolutional 15-1/6; Concatentated with Reed Solomon (223/255); Turbo 1/3; Turbo 1/6
  - Update/demonstrate OMSPA Software Receiver capability to extract Doppler suitable for nav.
  - Develop a simulated recording of 10 simultaneous Iris radio transmissions, each at a specific X-band frequency and each with a simulated Doppler shift.
    - Use Dave Heckman's analysis of in-beam time for the EM-1 cubesat deployment as a starting point for simulating the Doppler shifts.
  - Demonstrate that the OMSPA Software Receiver can be used to recover all of the frames from each of the 10 simulated simultaneous transmissions, as well as the Doppler signature for each.

OMSPA Proof-of-Concept Demonstration 2 (3/3)

- **Demonstration Plan: (Continued)**
  - Using the frame composition of the source recordings, validate the frame composition for each of the 10 demodulated and decoded signals.
  - Similarly, validate that the recovered Doppler signatures match the simulated Doppler shifts.
  - Document results & implications in a study report and publish in the *Interplanetary Network Progress Report* and/or other venues.
- **Results (Zaid Towfic's Briefing)**

OMSPA Proof-of-Concept Demonstration 3 (1/3)

Data Recovery from At Least 3 Simultaneous Mars Spacecraft Transmissions



- **Objective:** Demonstrate that OMSPA can be successfully applied to multiple, in-beam, "traditional" robotic spacecraft that are simultaneously downlinking with significantly different signal strengths.

OMSPA Proof-of-Concept Demonstration 3 (2/3)

- **Demonstration Plan:**
  - Update OMSPA Software Receiver with capability to handle the modulation and coding schemes of the 3 Mars spacecraft to be used in the demo.
    - Mars Reconnaissance Orbiter
    - Mars Odyssey
    - Mars Express
    - Consider MAVEN to be the "host" spacecraft.
  - Update BIPS and 7-DSC for identifying the intercept opportunities for the demonstration and provide a listing of those opportunities.
  - Use the WVSR to provide a recording of the appropriate intercept opportunities. Note the playback times from each Complex. Also, note the transfer times to the OSR work station.

OMSPA Proof-of-Concept Demonstration 3 (2/2)

- Demonstrate that the OSR can be used to recover all of the frames from each of the 3 or 4 spacecraft transmissions, as well as the Doppler signature for each. Note the frame recovery time in each case.
- Obtain the actual frame sequence and Doppler data from each of the 3 spacecraft transmissions and compare with that recovered from the WVSR recordings. Note the percentages of correctly recovered data.
- Repeat the demonstration for each of the three Complexes.
- In the process of conducting the demonstrations, identify any procedure and/or equipment changes needed to field an operational capability.
- Document results & implications in a study report and publish in the *Interplanetary Network Progress Report* and/or other venues.

- **Results (TBD)**

Topics

• OMSPA Proof-of-Concept Demonstrations 2 and 3 – Multiple Cubesats with a Strong-Signal Spacecraft	4/28/2017
• OMSPA Software Receiver Prototype that Includes Doppler Extraction	4/28/2017
• Prototype OMSPA User Interface – "One-Stop Shop" for Unscheduled, Opportunistic Use of Scheduled Beams (Test via Simulated "MOCs" at JPL and MSU)	9/29/2017
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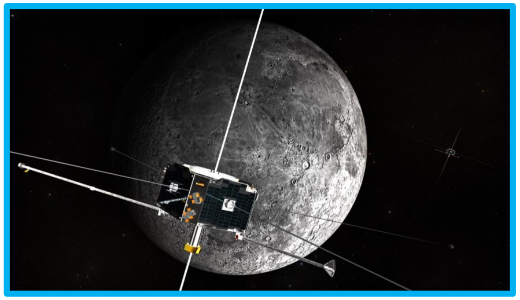
OMSPA Prototype User Interface (1/4)

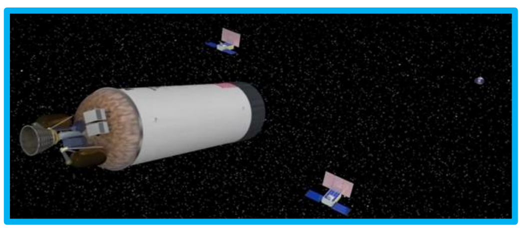
Moving to a Combination of JPL and Non-JPL Antenna Sites and User "MOCs"

Demonstration #4

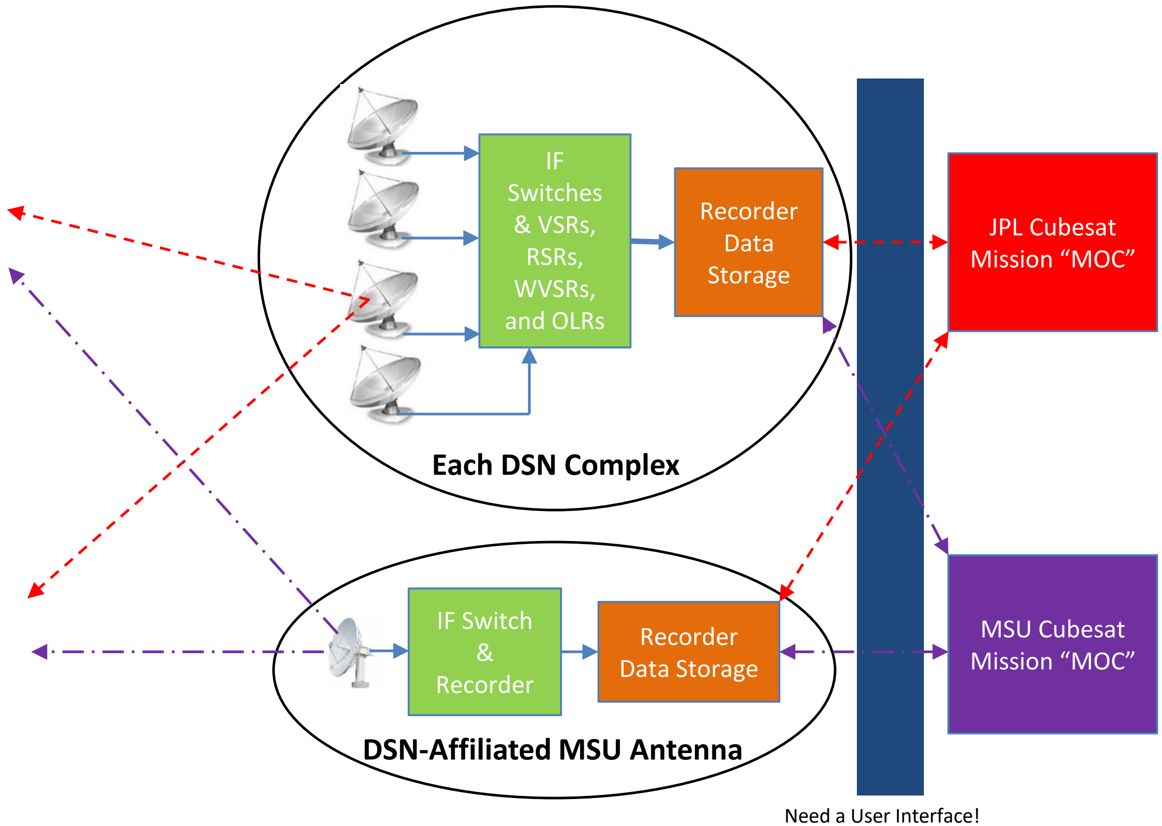


THEMIS B or C in LRO's Beam

Demonstration #5



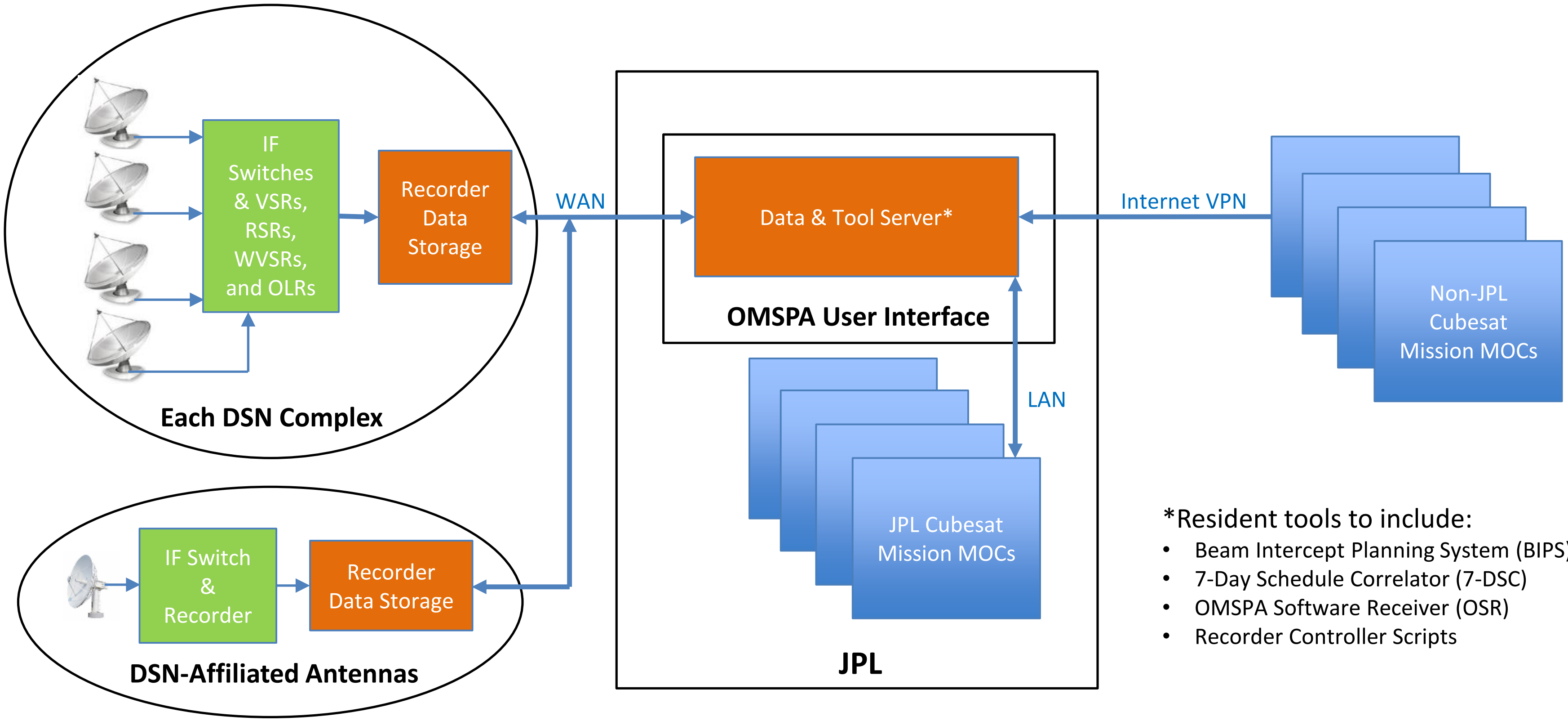
MarCO A and B in InSight's Beam



In the proposed FY'18 demonstrations, an OMSPA user interface would tend to simplify "multi-MOC" planning for, and interactions with, multiple site recorders.

OMSPA Prototype User Interface (2/4)

Objective: In preparation for the MSU & JPL "MOC" demos, development and testing of: (1) executable OMSPA tools with GUIs and (2) a secure server from which they can be remotely accessed.



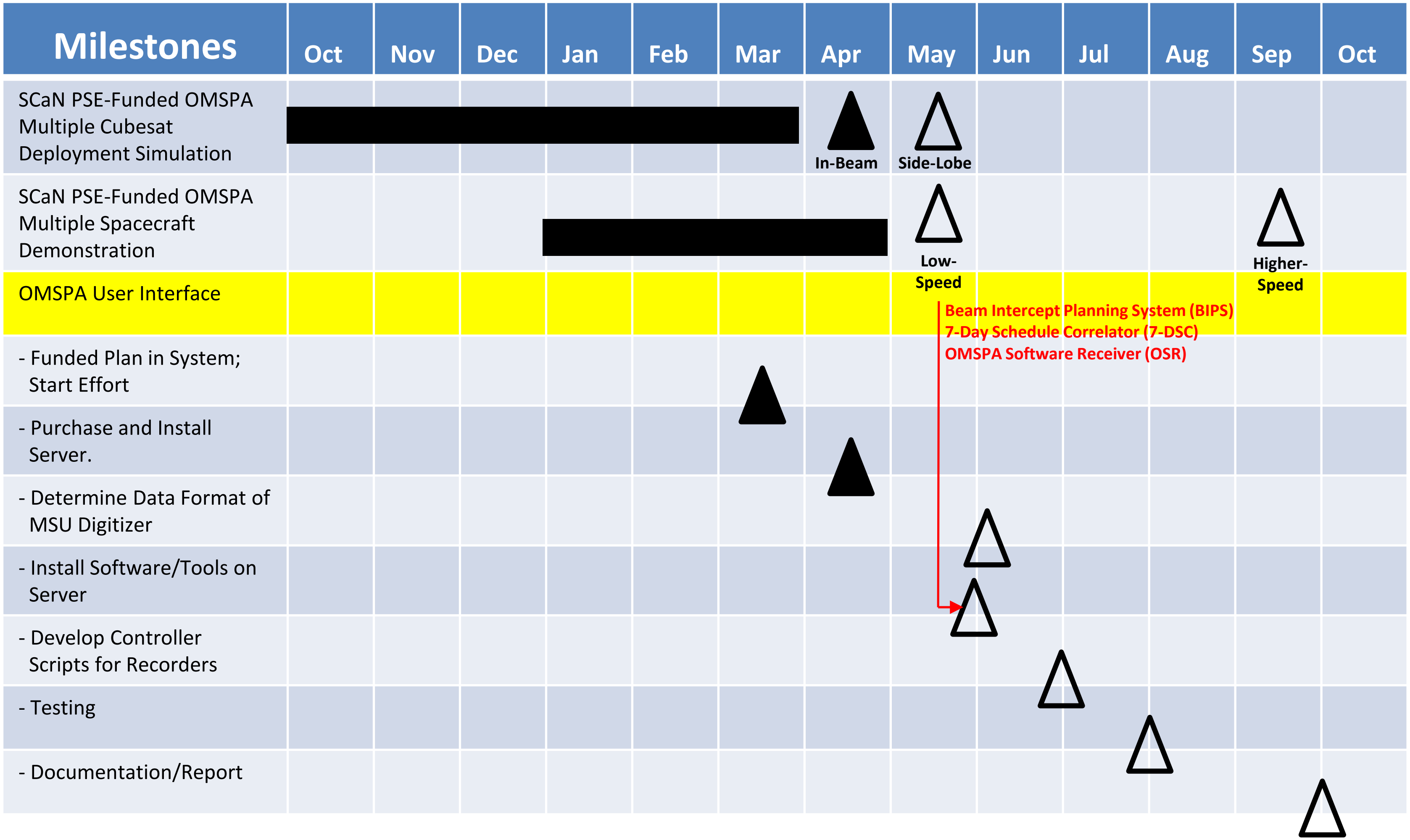
*Resident tools to include:

- Beam Intercept Planning System (BIPS)
- 7-Day Schedule Correlator (7-DSC)
- OMSPA Software Receiver (OSR)
- Recorder Controller Scripts

OMSPA Prototype User Interface (3/4)

- **Development and Testing Plan:**
    - Create a server-based, remotely accessible version of the Beam Intercept Planning System (BIPS) along with a user-friendly GUI for operating it. Test it by applying it to the previously discussed OMSPA Proof-of-Concept Demonstration #3.
    - Create a server-based, remotely accessible, change-protected version of the 7-Day Schedule Correlator (7-DSC) to use in conjunction with BIPS. Test it by applying it to the previously discussed OMSPA Proof-of-Concept Demonstration #3.
    - Create a server-based, remotely accessible version of the OMSPA Software Receiver (OSR) along with a user-friendly GUI for operating it. Test it by applying it to the previously discussed OMSPA Proof-of-Concept Demonstration #3.
    - Develop a secure server for registering OMSPA users, hosting the above tools, enabling remote access to them, and providing scripts for scheduling recorders and retrieving the authorized time and frequency portions of the digital IF recordings. Test it by applying it to the previously discussed OMSPA Proof-of-Concept Demonstration #3.
    - Conduct subsequent testing via Demonstration #4 and #5.

OMSPA Prototype User Interface (4/4)



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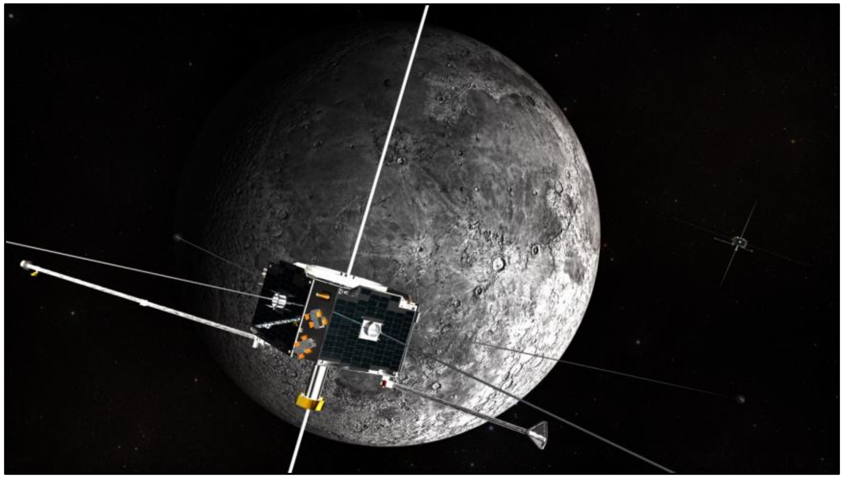
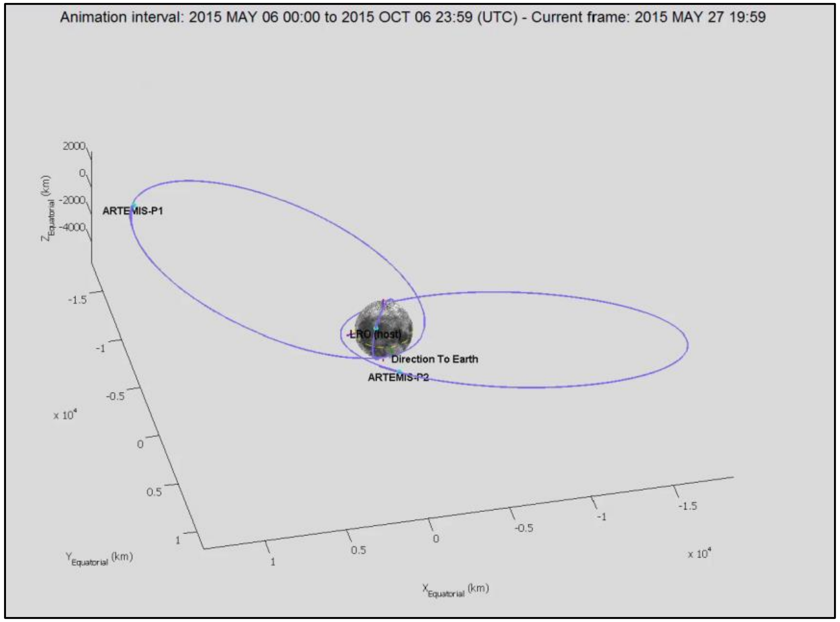
Demonstration #4 Prospects (1/3)





THEMIS B and C (a.k.a., ARTEMIS P1 and P2)

- In lunar orbit; DSN-supported; in extended-extended-extended mission.
- LRO, THEMIS B or C occasionally in same beam.
- Cursory link analysis suggests MSU 21m can close link at reduced data rate. (See next slide)
  - S-band feed use would need to fit into the overall X-band capability development schedule.
  - Would need to obtain THEMIS Project agreement transmit at reduced rates during intercept periods.
  - Another possible approach would be to use THEMIS B or C as the “host” spacecraft and LRO as the OMSPA participant.

Demonstration #4 Prospects (2/3)

Preliminary THEMIS S-band Downlink Results with MSU 21m Antenna

Morehead State University Space Science Center
21 Meter Space Tracking Antenna
(Latitude: 38° 11 30.773 N,
Longitude: 83° 26 19.948 W) U.S.A

FUNCTION	PERFORMANCE
Antenna Diameter	21 Meter
Receive Polarization	RHCP,LHCP,VERT,HORZ
Travel Range	AZ +/- 275 degrees from due South (180 deg) EL -1 to 91 degrees POL +/- 90 degrees
Velocity	AZ Axis = 3 deg/sec EL Axis = 3 deg/sec POL Axis = 1 deg/sec
Acceleration	AZ = 1. 0 deg/sec/sec min EL = 0.5 deg/sec/sec min
Display Resolution	AZ/EL = 0.001 deg POL = 0.01 deg
Encoder Resolution	AZ/EL = 0.0003 deg (20 Bit)
Tracking Accuracy	<= 5% Received 3 dB Beamwidth (0.028 deg RMS L-band) (0.005 deg RMS Ku-Band)
Pointing Accuracy	<= 0.01 deg rms

21 M Space Tracking Antenna

The Space Science Center at **Morehead State University** has developed a full motion 21-meter class antenna system which is engaged in a rigorous research program in radio astronomy and also serves as an Earth Station for satellite mission support as well as a test bed for advanced RF systems. The instrument is staffed by university faculty and students and is available for a wide variety of TT&C services. Performance Characteristics are provided below:

21 M Mission Operations Center

Control Room at 21 M

21 M Antenna System Radio Frequency Operating Regimes

Radio Frequency (RF) Band	Bandwidth	
	Low End	High End
L-Band	1.4 GHz	1.7 GHz
S-Band	2.2 GHz	2.5 GHz
X-Band	7.0 GHz	7.8. GHz
Low C-Band	4.8 GHz	5.0 GHz
Ku-Band	11.2 GHz	12.7 GHz

Radio Frequency Performance at L-Band and Ku-Band

Radio Frequency (RF) Performance Criterion	Measured Parameters	
	L-Band	Ku-Band
Frequency	1.40 GHz	11.2 GHz
Antenna Gain	47.80 dBi	65.50 dBi
LNA Temperature	25 K	70 K
System Temperature, T_{sys}	83.8 K	139.0 K
G/T at 5° Elevation	28.6 dBi/K	44.1 dBi/K
HPBW	0.62°	0.08°

Radio Frequency Performance at S-Band and X–Band

Radio Frequency (RF) Performance Criterion	Theoretical Parameters	
	S-Band	X-Band
Frequency	2.4-2.7 GHz	7.1-7.6 GHz
Antenna Gain	52.8 dBi	62.0 dBi
System Temperature, T_{sys}	215K	215K
N_o	-175dBm/Hz	-175dBm/Hz
G/T at 5° Elevation	29.5dBi/K	38.7dBi/K
HPBW	0.37°	0.13°

For Scheduling or Cost Structure contact:

Assumed Parameters for Link Budget

THEMIS Data Rates

Low Data Rate	High Data Rate
1.024 kbps	131.072 kbps
4.096 kbps	262.144 kbps
8.192 kbps	524.288 kbps
16.384 kbps	1048.576 kbps
32.768 kbps	
65.536 kbps	

Typical downlink rate

Maximum Supportable Rate with 21m

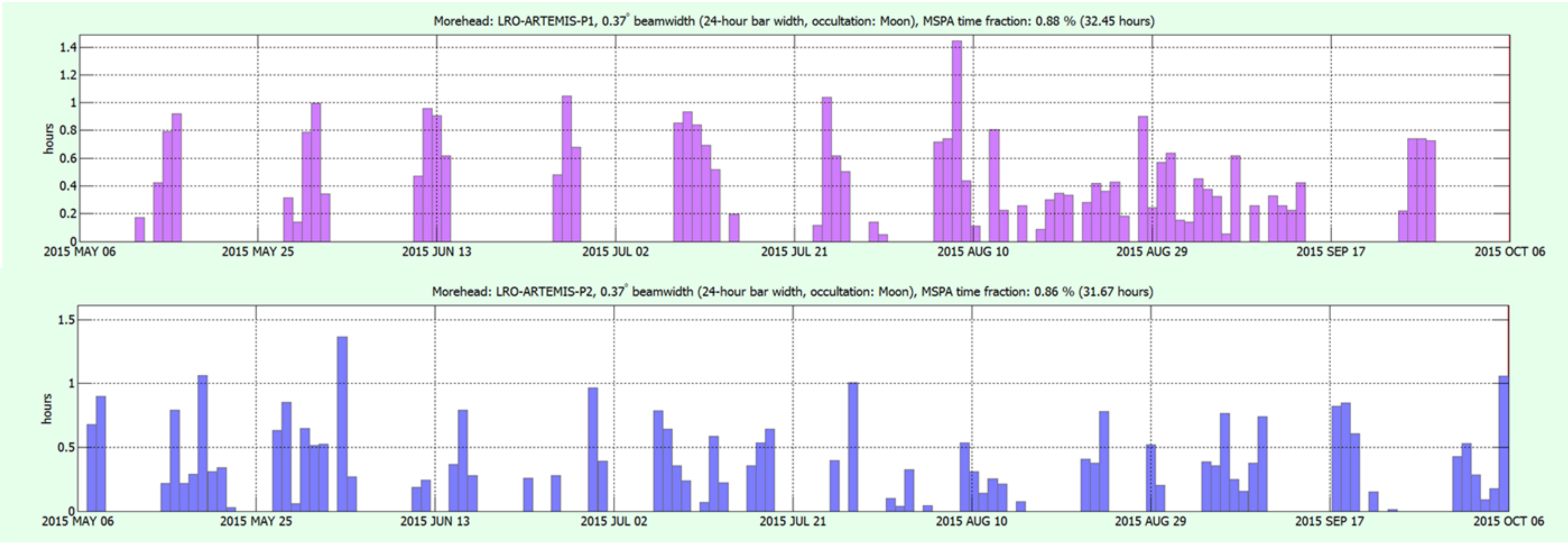
Data Rate (bps)	Antenna Gain (dBi)	Max Range (AU)
1024	0	0.016
4096	0	0.008
8192	0	0.006
16384	0	0.004
32768	0	0.003

Moon = 0.00257 A.U.

Note: The OSR would need to be extended to handle PCM/PSK/PM.

Demonstration #4 Prospects (3/3)

Example Beam Intercept Opportunities (in hours) Over a 5-Month Period



- With THEMIS as the OMSPA target, demo potentially satisfies weak/strong spacecraft signal conditions while proving out the feasibility of the OMSPA "self-service" approach for routine downlink by university cubesats.
  - Note: Need to establish whether LRO and THEMIS ever simultaneously transmit during the overlap periods. If not, such transmission would have to be pre-arranged with the THEMIS project.

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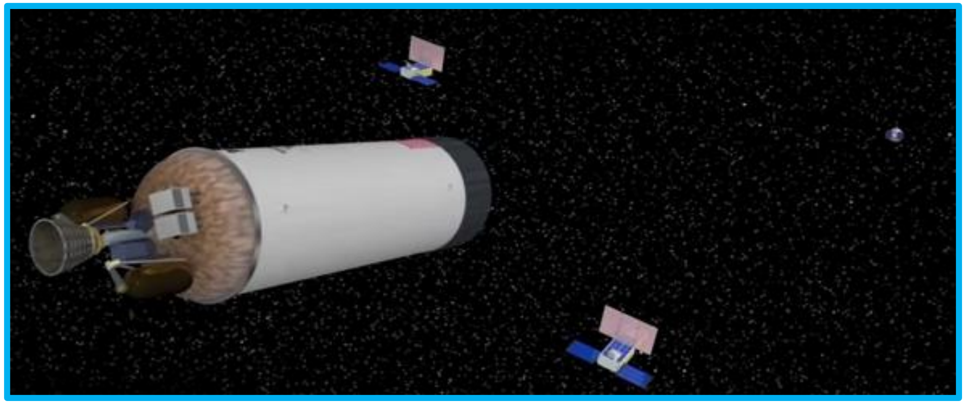
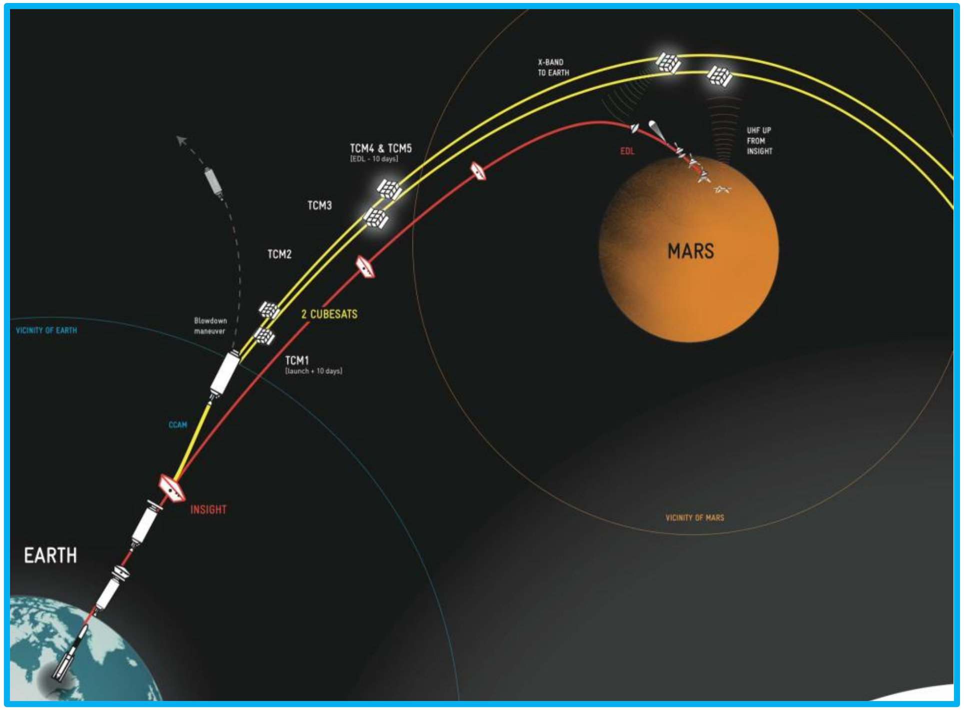
Demonstration #5 Prospects (1/2)





MarCO A & B in route to Mars

- Launched off of Upper Stage for InSight.
- In InSight’s beam for entire transit to Mars. (Need to verify.)
- Cursory link analysis suggests MSU 21m can close link for days to weeks depending upon actual data rates and spacecraft antenna in use. (See subsequent slide.)
- Would provide test of multi-spacecraft OMSPA capability in the presence of a strong signal (i.e., InSight).
- MarCO Mission Overview (Sami Asmar)

Demonstration #5 Prospects (2/2)

Preliminary MarCO X-Band Downlink Link Results with MSU 21m Antenna

Data Rate (bps)	Antenna Gain (dBi)	Max Range (AU)	Days Since Launch
62.5	28	0.9	197
1000	28	0.3	117
8000	28	0.1	62
62.5	9	0.10	62
1000	9	0.041	25
8000	9	0.015	8
62.5	7	0.079	49
1000	7	0.032	19
8000	7	0.011	6

Assumed Gain = 65 dBi; Noise temperature = 100°K; Antenna efficiency = 65%

Suspected in-cruise operational rate and antenna types. (Need to verify.)

Assuming a 1 kbps downlink rate during cruise, MSU's 21m antenna will be able to support an OMSPA demo for the first 3-4 weeks of flight.

Summary

- OMSPA demonstrations to date have helped prove out the concept, establish the planning toolset, and motivate development of the OMSPA Software Receiver.
- Establishing a prototype user interface that allows both JPL and non-JPL MOCs to plan and conduct OMSPA operations on both DSN and DSN-affiliated antennas is the next logical step.
  - Understanding the MSU 21m antenna and its associated recording capabilities are a key part of this.
  - Bandwidth, channelization, and signal processing speed are key considerations as we move forward.
- Demonstrations 4 and 5 help provide context and motivation for the user interface development.
  - These demonstrations may need to be tailored as capabilities and challenges become better understood.